A Physically Based Approach for Modeling Multiphase Fracture-Matrix Interaction in Fractured Porous Media

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RESEARCH OBJECTIVES

The objective of this study is to develop a physically based upstream weighting scheme. Such a scheme would be used for determining relative permeability functions or mobility terms that could be generally applicable to calculating multiphase flow between fractures and the rock matrix, using a dual-continuum concept. The physically based numerical approach overcomes the limitation of most numerical models for dealing with fracture-matrix interaction in selecting correct relative permeability values. Most such models use a single-point upstream weighting scheme by which to estimate flow mobility for fracture-matrix flow terms. However, such a scheme is prone to selecting incorrect mobilities for calculating fracture-matrix flow, which may lead to unphysical solutions or significant numerical errors.

APPROACH

Our modified upstream weighting scheme by which to select the appropriate mobility for fracture-matrix interaction is based on (1) the principle that the capillary pressure is continuous at the fracture-matrix interface and (2) the assumption that there is an instantaneous local pressure equilibrium for each phase on the matrix surface between fracture and matrix systems. These conditions should be reasonable for most fractured reservoirs, because fracture aperture is normally small, and dynamic changes in fractures, such as capillary pressures, could be instantaneously equilibrated locally at contacted matrix surfaces. Therefore, the new scheme, when the upstream direction for fracture-matrix flow is at fractures, uses a matrix relative permeability function as a function of fracture capillarity to calculate the mobility. Physically, this approach is equivalent to evaluating flow through the fracture-matrix interface into the matrix with the effective matrix permeability at that interface, which is still an upstream weighting scheme.

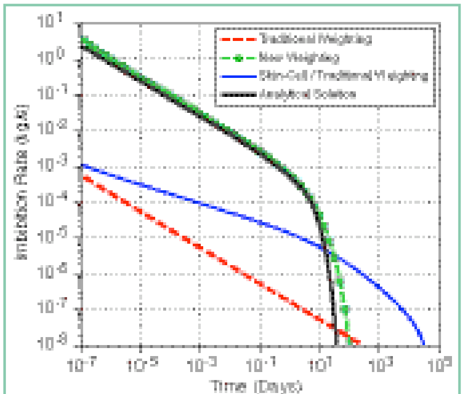

Figure 1. Comparison of calculated water imbibing rates from analytical and numerical solutions into a cubic matrix block

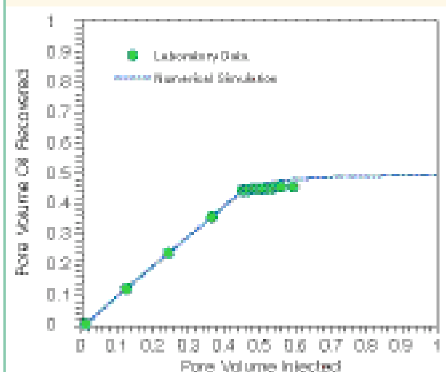

Figure 2. Comparison of simulation results with experimental data (Kazemi, 1979)

ACCOMPLISHMENTS

This physically based modeling approach for estimating physically correct relative permeability, in calculating multiphase flow between fractures and the matrix, has been implemented into two multiphase reservoir simulators. It has also been verified using both analytical solutions and laboratory experimental data (see Figure 1 for comparison of the proposed model results with laboratory tests involving a water-oil displacement experiment using fractured cores). The new method is demonstrated to be accurate, numerically efficient, and easy to implement in dual- or multiple-continuum models.

SIGNIFICANCE OF FINDINGS

The physically based upstream weighting scheme overcomes a serious flaw that exists in most current, conventional simulation practice when estimating flow mobility for fracture-matrix flow terms. Numerically, the new scheme uses exactly the same dual-continuum grids as the traditional dual-continuum approaches. Without requiring an additional computational burden or using refined grids, we achieve not only accurate but also physically correct results for fracture-matrix interaction.

RELATED PUBLICATION

Wu, Y. S., L. Pan, and K. Pruess, A physically based approach for modeling multiphase fracture-matrix interaction in fractured porous media. Advances in Water Resources, 27, 875–887, 2004. Berkeley Lab Report LBNL-54749.

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